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# An inventory model for analyzing the benefits of extending limited shelf-life hazardous material in the DoD supply system

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# NAVAL POSTGRADUATE SCHOOL
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# THESIS

**AN INVENTORY MODEL FOR ANALYZING THE BENEFITS OF EXTENDING LIMITED SHELF-LIFE HAZARDOUS MATERIAL IN THE DOD SUPPLY SYSTEM**

by

Donn D. Murray

June, 1995

Thesis Co-Advisors: Alan W. McMasters
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This thesis presents an analysis of the current DoD shelf-life extension program. It examines the methodology used to determine if a specific hazardous material managed by the DoD can be extended past normal expiration and the value gained by such an extension. The effect of the extension in terms of the effects on inventory management and the cost/benefits in terms of the shelf-life program costs to inventory savings are analyzed. A hazardous material inventory model is developed for material with extendable shelf-life, based on a stochastic version of the Economic Order Quantity model commonly used for inventory management of consumable items where time-weighting of backorders is not important.

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# AN INVENTORY MODEL FOR ANALYZING THE BENEFITS OF EXTENDING LIMITED SHELF-LIFE HAZARDOUS MATERIAL IN THE DOD SUPPLY SYSTEM


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## ABSTRACT

This thesis presents an analysis of the current DoD shelf-life extension program. It examines the methodology used to determine if a specific hazardous material managed by the DoD can be extended past normal expiration and the value gained by such an extension. The effect of the extension in terms of the effects on inventory management and the cost/benefits in terms of the shelf-life program costs to inventory savings are analyzed. A hazardous material inventory model is developed for material with extendable shelf-life, based on a stochastic version of the Economic Order Quantity model commonly used for inventory management of consumable items where time-weighting of backorders is not important.

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# I. INTRODUCTION

## A. THE PROBLEM

The Navy and DoD have a vested interest in reducing the levels of inventory held at the wholesale and retail level. Part of this inventory can be categorized as shelf-life material (i.e., material with a limited storage life prior to usage). Within the category of shelf-life material exists the subcategory of hazardous material. A hazardous material is identified as an item that may cause or significantly contribute to increased mortality due to its physical, chemical, or infectious characteristics in certain quantities or concentrations. Such an item may also cause or contribute to serious, irreversible, or incapacitating illness, or pose other substantial hazards to human health or the environment when improperly treated, stored, transported, disposed of or otherwise managed. As a consequence, hazardous material represent a substantial environmental responsibility and expense to DoD.

The Navy and DoD have previously followed materials management policies which have produced large inventories of hazardous material with expired shelf-life, resulting in high disposal costs. Recently, the Navy has established a pollution prevention program for hazardous material and seeks to minimize excess inventory generation through inventory control, modification of existing system requirements, and efficient disposal. Disposal costs are constantly increasing and the realities of environmental pollution impacts make disposal the least desirable alternative.

In an effort to decrease the quantity of material disposed of as expired shelf-life hazardous material, the Defense Logistics Agency (DLA) and the Naval Supply Systems Command (NAVSUP) have implemented a study program through the Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA, to analyze the shelf-life specifications for materials found to have a high frequency of disposal. The results of these analyses and the potential for shelf-life extension through retesting can be expected to provide short term shelf-life extensions for the current inventory and long term cost reductions through disposal costs avoidance.

The NAVSUP and DLA have also provided considerable support to the investigation of methods that will reduce hazardous materials inventory through the use of vendor direct-delivery contracts, revision of safety stock inventory levels, improved methods for monitoring the shelf-life of existing hazardous materials inventory, and for reutilization of expired or recycled hazardous materials rather than disposal (Pipan, 1995).

## B. THESIS OBJECTIVE

The purpose of this thesis is to develop a cost/benefit model for evaluating the extension of a Hazardous Material's (HAZMAT) shelf-life in both the Navy and Defense Logistic Agency (DLA) supply systems. This model is based on the stochastic version of the well-known Economic Order Quantity (EOQ) inventory model and includes the disposal costs and savings from increased shelf-life. It is intended that the model to be used to determine the justification for modifying the Navy shelf-life program during the acquisition phase. This acquisition program modification is not discussed as part of this thesis, but is anticipated to be an extension of the previously dictated shelf-life requirements in existing Military Specifications (MILSPEC's), engineering specifications, or other procurement requirements.

## C. RESEARCH QUESTIONS

This thesis examines the following research questions:

1. What method is the civilian sector using for shelf-life assignment and extensions? What is the process by which they determine that a material is HAZMAT?

2. What are the costs associated with the inventory management of shelf-life material?

3. What are the cost factors to consider when developing the cost/benefit model for justification of continuing the Navy shelf-life material review program?

4. How will inventory managers and end users of limited shelf-life material access shelf-life extension test data?

5. What does the inventory manager do when the shelf-life is extended for a material expected to expire in a given period?

6. What criteria have been used by DLA and GSA in determining acceptance or rejection of shelf-life change recommendations based on contractor analysis sponsored by Naval Facilities Engineering Service Center (NFESC)?

7. How much of a reduction in HAZMAT disposal costs can be expected to be achieved through extension of shelf-life specifications at the acquisition phase?

## D. SCOPE OF THE STUDY

This study develops a Stochastic Economic Order Quantity model that can be applied to the determination of shelf-life material order quantities. This model may prove applicable for determining the cost/benefit justification of DoD shelf-life program reviews and continuation of the NFESC shelf-life analysis program. The actual cost/benefit analyses done here are limited to the results obtained to date from contractor analyses of materials experiencing high volume disposal and identified through the Defense Reutilization Management System (DRMS). A cost/benefit analyses compares the costs of hazardous material disposal avoidance from accepted shelf-life management changes and shelf-life extensions to the costs of the contractor investigations.

## E. METHODOLOGY

A stochastic inventory model is used in determining the expected increased benefits of shelf-life extension due to higher consumption of existing inventory and decreased cost of disposal and replacement of unused inventory. The cost of excess material in this case is the disposal cost since the model assumes that there is no salvage value for the material.

NFESC has conducted surveys of numerous DoD disposal facilities for HAZMAT as part of their NAVSUP-sponsored shelf-life study. The results of HAZMAT shelf-life studies by Arthur D. Little Inc. (1992) and Engineering Science Inc. (1995), under contract to NAVSUP and NFESC, indicate numerous material shelf-lives based on outdated specifications can be lengthened or completely removed. This research analyzes data available from NAVSUP, NFESC and the Defense Logistics Agency (DLA) to estimate potential savings resulting from the use of the model.

The decision tree for managing shelf-life material is shown in Figure 1.1 It forms the basis for the model development and problem analysis.

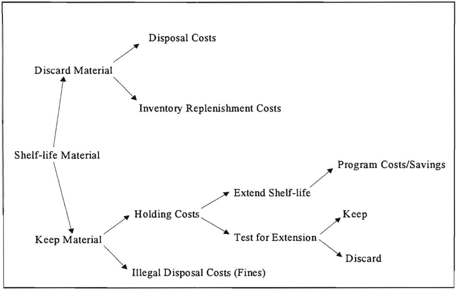



Figure 1.1 Shelf-Life Analysis Model.

The following assumptions are used in the model development:

1. Demand is stochastic. It is assumed that the material always has a demand rate which can be modeled using a known probability distribution.

2. Holding costs are known and remain constant over time. Purchasing costs for new inventory material are known and remain constant over time.

3. Disposal costs are known and remain constant over time.

4. Illegal disposal fines are prohibitively high.

5. Laboratory costs for testing/extension analysis of shelf-life materials are known and remain constant over time.

## F. THESIS OVERVIEW

This thesis is divided into seven chapters. Chapter I has presented the problem, stated the objective of the thesis and the associated research questions, and previewed the research methodology. Chapter II discusses the issues associated with shelf-life extensions and the procedures for getting approval of such extensions. Chapter III discusses the existing shelf-life extension programs and the results of the author's cost/benefit analysis based on the A. D. Little study. Thhe chapter also discusses the Quality Status List which contains the results of past shelf-life tests. Chapter IV examines the inventory cost parameters associated with the management of hazardous material. These become part of the model in Chapter VI. Chapter V discusses previous inventory models developed by other authors. Chapter VI presents a stochastic inventory model for establishing the optimal order quantity and reorder point for an established service level. The iterative process for determining the optimal order quantity and reorder point is described and a sample calculation presented. Chapter VI also presents two models for deciding whether or not it is economical to conduct testing for the purpose of extending the shelf-life of an item. Chapter VII presents a summary of the thesis efforts, conclusions from the research, and recommendations for further study.

# II. DOD HAZARDOUS MATERIALS MANAGEMENT

## A. BACKGROUND

The Naval Supply Systems Command (NAVSUP) is tasked to manage the inventory and disposition of Navy owned materials held at the wholesale and retail levels. The Navy's Hazardous Material Control and Management Program is established by OPNAVINST 4110.2 (1992). This program is responsible for defining the policy, guidance, and requirements for life-cycle control and Total Quality Management (TQM) of hazardous material acquired and used by the Navy. This instruction also directs that controls are established to reduce the amount of hazardous material used and the related quantity of hazardous waste that is generated (DoD 4140.27-M).

Hazardous material management has generally concentrated on the areas of collection, management and disposal of the hazardous waste generated by command activities. Prior to 1991, hazardous material control was conducted at the local level throughout the Navy and other services. In this effort individual commands, ships, and shop facilities were responsible for controlling their in-use and safety stock inventory levels, establishing individual ordering policies, and disposing of waste/excess as directed by their local policies. This generally resulted in excess material being held at the wholesale and retail/user level, contributed to disposal costs for excess and expired shelf-life material, and exposed the Navy to environmental pollution violations. These violations were primarily due to inadequate management of the waste material and training of the individuals at the user level even though DLA Regulation 4155.37/NAVSUPINST 4410.56 provides reference material for the proper stowage of hazardous material to preclude the potential for waste generation.

As a consequence of the hazardous material and hazardous material problems, it became clear that inventory and disposal controls were required. Source reduction, as identified in the Pollution Prevention Act of 1990 (PL 101-508, 1990), emphasized reducing the quantity of hazardous substances released into the environment prior to recycling treatment or disposal.

In an effort to control the Navy's user level inventory and disposals, the Hazardous Material Minimization Center (HAZMINCEN) concept was implemented at Naval Air Weapons Station (NAWS) Point Mugu. This centralized management and distribution system has evolved into the Consolidated Hazardous Material Reutilization and Inventory Management Program (CHRIMP). The program has since expanded from shore to afloat facilities. The HAZMINCEN concept focuses on controlling the issue and reutilization of partially used hazardous materials. If the material is from regular A-condition inventory the customer is charged the stock price. However, if the customer chooses to accept material from the consolidation and reuse stock it is considered to be cost avoidance (CA-condition) material and the issue is processed at no charge to the customer (DoD 4140.2-M).

The central database used in the CHRIMP system is the Hazardous Inventory Control System (HICS). HICS is used to manage the receipt and inventory status of the material, and to generate the documentation required for all issues and waste disposal based on an individual bar code tracking number for each individual item. Similar programs exist in industry and are used to track both individual material and quantify the release of Volatile Organic Compounds (VOCs) into the atmosphere. The HICS tracking program has served to reduce the user inventory levels and protect the Navy against costly hazardous material disposal fees.

## B. SHELF-LIFE AND HAZARDOUS MATERIALS MANAGEMENT

In commercial management, shelf-life materials are generally referred to as "perishable materials". Perishability refers to the physical deterioration of the material while being held as inventory awaiting issue or after issue and awaiting usage by the end user. Considerable work has been conducted by Nahmias (1975, 1982) in the area of perishable inventory controls, optimal ordering policies, and optimal issuing policies for perishable materials such as blood bank inventories. For the purpose of this thesis, perishable materials are referred to by the military term of shelf-life material. Product shelf-life is defined as the amount of time that an item can remain on the shelf in the packaged state from the date of

manufacture/cure/assembly/pack until deterioration beyond usefulness is expected to occur. Upon expiration of the shelf-life the item must be disposed of or tested for reuse.

Shelf-life items can be divided into two separate categories of materials depending on the lifetime of a unit of the item. There are materials with fixed lifetimes, where the utility of the unit is constant for a fixed period, then decreases appreciably or requires disposal. Examples include blood, produce, chemical and rubber products. In contrast, other items have a lifetime based on random variables (environmental and internal chemical reactions) and the utility of the material can decrease in a manner that may not depend on the age of the unit involved. Examples include drugs, volatile chemicals, and items requiring special temperature controls. This decreased utility can be as simple as material separation in liquid stocks due to chemical additive breakdown or reduced viability of vaccines kept at room temperature in lighted conditions. In the military stock system, shelf-life materials fall for the most part into the initial category: items of fixed known lifetime, with constant utility during the shelf-life and little utility after expiration, except when reuse for lesser applications is possible or when the condition of the material has actually not deteriorated by the end of its designated shelf-life (i.e., designated shelf-life is less than actual useful shelf-life).

Stocked materials in the DoD Supply System are assigned unique National Stock Numbers (NSN's) and have a designated shelf-life code if they meet the criteria defined in the Military Standards (MILSTD) for military material specifications. Shelf-lives are assigned by the material item manager, manufacturer, or other organization following a technical evaluation of an item's characteristics for deterioration or instability. These technical evaluations may be provided by the manufacturer based on the military specification (MILSPEC) or other performance specification requested by the requisitioner and designated by the inventory manager when requesting the material. The focal points for these shelf-life assignments can be found in the Shelf-Life Management Manual, DoD 4140.27-M.

These shelf-life items require controlled management from the time the item is introduced into the system through storage/issue and ultimately disposal. The key to minimization of government expense and losses is the establishment of accurate requirements

forecasts, efficient usage and recycling efforts, and the proper assignment of material specifications that form the basis for acquisition.

Inventory management at the wholesale and retail levels in the military have historically not followed the First-In, First-Out (FIFO) method of issuing materials, resulting in a large quantity of aged materials that are close to or have expired shelf-lives. Similarly, reduction of inventory levels may lag behind the actual reduction of demand requirements because of the inventory management and demand forecasting models employed to determine inventory levels and related reorder requirements. War reserve materials also impact on the average age of an individual item in the system due to the large quantity of materials required to maintain the war reserve levels. Responsible inventory managers must ensure that stocks are rotated to prevent large quantities of expired shelf-life materials in the war reserve stocks.

Once material is issued from a wholesale activity, shelf-life management is the responsibility of the material holder. The consumer level (the end users) must strive to maintain the proper stowage and issuing procedures. In addition to the FIFO rule this level must ensure that serviceable, "A" condition shelf-life inventory items are issued. Numerous DoD manuals such as DoD 4140.27-M have been issued to assist an end user in the proper management of shelf-life commodities. Consistent with this is the goal of consolidating wholesale inventories at the least number of geographic locations and closest to the source of demand. Maximum use of direct vendor delivery is a current initiative to reduce consumer level inventories and will be increasingly applied to reduce the potential for excess stock levels (Pipan, 1995).

Shelf-life materials are separated into two categories, Type I and Type II. Type I material is considered to be non-extendible after its defined shelf-life period. These materials will be destroyed or turned into the Defense Reutilization Management Office (DRMO) for sale or disposal at the end of their life. Type II material is considered to be extendable after completion of inspection/test/restorative action. When Type II material has reached its maximum allowable extended life, then it must also be disposed of. The maximum shelf-life for materials was previously established at 60 months. However, this was changed effective January 1995, to a maximum length of 120 months (Lewis, 1995). The decision to extend

existing shelf-lives of current inventory materials should be based on detailed laboratory analysis, end user adherence to environmental storage standards, and engineering support activity experience.

## C. NAVAL FACILITIES ENGINEERING SERVICE CENTER STUDY

NAVSUP has the responsibility for validating the shelf-life terms assigned to the hazardous material utilized by the Navy. As mentioned earlier, unnecessary disposal of hazardous material due to incorrect shelf-life specification results in increased disposal costs, increased stock replacement costs, increased stock levels, and pollution of the environment. The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA has been funded by NAVSUP and the Naval Facilities Engineering Command (NAVFAC) to analyze the shelf-lives of certain hazardous materials and conduct chemical analyses related to the same hazardous material. NFESC has pursued this assignment through both in-house and contracted laboratory services for testing and evaluation of material for performance, shelf-life, and evaluation of established specifications required by the MILSPEC, engineering requirements, or the manufacturer. The concentration of the NFESC study has initially been on materials with large disposal volumes found at various Hazardous Material Disposal Centers and Defense Reutilization Management Office facilities (DRMOs). NFESC currently has three areas of study:

1. Designated shelf-life changes or extension,
2. Reutilization potential of expired material, and
3. Development of a model for economic procurement, testing, and disposal.

Other studies have been initiated in the areas of shelf-life code analysis, use of CD-ROM format databases and microfiche for dissemination of shelf-life information, shelf-life test data consolidation and electronic accessibility, increased shelf-life and hazardous material

training, and development of deterioration sensing equipment for shelf-life material (Pipan, 1995).

The goal of the NFESC development program is the justification for shelf-life extension during acquisition standards modification or through testing of existing inventories. Some of the primary costs involved in such a program are costs due to testing, material and purchasing specification reviews, stowage of batch test material, database management, personnel labor, property overhead, transportation, disposal, and material handling. One result of the NFESC investigations has been the recommendation that DoD adopt commercially established shelf-life values instead of the often outdated MILSPEC or other acquisition requirement.

## D. CHANGING THE SHELF-LIFE OF HAZARDOUS MATERIAL

The process for changing the shelf-life of material both in inventory and in the acquisition process is complex and lengthy. The policy direction for changing the existing shelf-life parameters is found in DoD Instruction 4140.27-M. This instruction breaks the shelf-life code "challenge" process into the following areas:

1. Wholesale/retail recommendations based on storage analysis and performance test results of expiring material.
2. Customer complaints and recommendations based on end use of material.
3. Laboratory and other scientific analysis recommendations from government or contracted sources.
4. Manufacturer's recommendations.
5. Item manager's recommendations.
6. Engineering Support Activity (ESA) recommendations.

7. Acceptance of challenges and changes to the shelf-life in the item managers and Inventory Control Point data base.

8. Dissemination of acceptance or rejection of changes.

The adjustment of existing shelf-life parameters poses a large hurdle to the reduction of HAZMAT disposals. This is due to the complexity of both the end use system's analysis and the length of time for the multiple reviews that must occur prior to adoption of any shelf-life change.

Before any change is adopted, the recommendation and supporting documentation must be reviewed by the Quality Assurance organization of the managing agency (i.e., Air Force, Army, Navy, DLA, GSA). Once completed, recommendations approved are forwarded to the responsible ESA for review and acceptance or rejection. The standards for such approval by the ESA are somewhat nebulous and the decision for acceptance or rejection is ultimately dependent on the criticality of the end use system's application. If the application is determined to be mission critical, the ESA is less likely to accept the recommendation based on a past history of good performance or scientific analysis under existing standards. The ESA will generally submit the change for review and analysis of potential for critical failure during a mission, effectively stagnating the process. This unresponsive decision system can be traced to years of habit, inter-agency rivalry, and a lack of trust in the accuracy and unbiased analysis on the part of the testing/analyzing facility.

The span of time for such multiple reviews can be in excess of 120 days before final acceptance of a proposed change and implementation occurs. This is truly remarkable in the case of those items that have undergone considerable laboratory analysis, scientific review, and item manager/Quality Assurance analysis prior to recommendation for change.

Once a material is accepted for extension of the existing shelf-life, existing inventories must be updated and acquisitions in-process should be modified to reflect the change. Based on conversations with item managers and wholesale/retail storage facilities (Lewis, 1995), the existing inventories are not immediately updated with the extensions until the next scheduled shelf-life review and the item managers do not transmit immediate acquisition changes to

commodity procurement agents. Additionally, the procurement agents are not required to amend existing delivery contracts or modify the requests for bids that have been issued for vendors. The contracts are allowed to be let based on the original specifications for bid or existing contracts. This results in large quantities of material that get forwarded to the waste facilities or Hazardous Minimization Centers due to outdated information and because it would require increased labor at the wholesale/retail level to re-label newly manufactured inventory material with the latest shelf-life.

# III. DOD SPONSORED SHELF-LIFE ANALYSES

## A. INTRODUCTION

The importance of reducing the amount of hazardous material that is cycled from the DoD shelf-life inventory to the hazardous waste stream is a primary goal of the DoD's Shelf-Life Committee. This goal has generated numerous shelf-life program initiatives, which include the analysis of the existing shelf-life type, assignment of the shelf-life length, and the criteria for allowing extensions of shelf-life. These factors are considered in separate studies by Arthur D. Little Laboratories and Parsons Engineering Science, Inc., and discussed in this chapter. Additionally, this chapter presents a cost/benefit analysis based on the A. D. Little study investment cost and the benefits gained from disposal and purchase cost savings resulting from shelf-life changes for specific commodities.

## B. SHELF-LIFE PROGRAMS

Commercial shelf-life is assigned based on a combination of factors encompassing environmental parameters, chemical activity, and packaging aspects. In general, most materials used in the private sector are not subject to the long shelf-life necessary to support the war reserve material inventory requirements of the DoD. In fact, the majority of commercial materials that have defined shelf-lives are limited to medical and food items that require constant environmental and rotational controls. More efficient inventory management and utilization of vendor direct-delivery contracts provide the obvious means to reduction of DoD shelf-life inventory. However, the perishability of both medical, volatile chemical compounds, and food stores materials routinely have expiration dates and require shelf-life management. These materials require similar analysis of the perishability factor into the shelf-life management models as done by Fries (1975).

Commercial wholesale storage activities generally ensure that material is rotated on a continuous basis, thereby reducing the opportunity for older materials to expire and require

disposal. Commercial activities that manage wholesale stocks in such a manner quickly experience the loss, recognize the need for proper storage and rotation, or quickly go out of business due to a lack of profits. Commercial retail activities that receive material that is not fit for sale have the capability of returning the defective material for replacement or credit by the manufacturer. The DoD does not have the capability to return most retail or end-user stocks for replacement by the manufacturer, based on the inadequate temperature controlled storage facilities operated by the DoD. The use of such facilities for storing temperature sensitive shelf-life materials at less than the optimal prescribed conditions greatly degrades the material and severely limits the potential for manufacturer acceptance of excess inventory (Stozeck, 1995).

Comparisons between the routine management of commercial materials that do not normally require a shelf-life assignment and the management of the same material by the DoD has been a constant source of discussion at numerous DoD shelf-life conferences. The broad assumption that the DoD should assign the same shelf-life as the civilian marketplace has merit, but does not account for the wide range of climatic and storage/handling conditions in which the DoD must manage the material. Commercial activities generally store the materials in more ideal conditions than the broad range of temperature extremes experienced in the major storage depot warehouses and ships afloat.

DoD laboratories, GSA chemists and other contracted agencies are constantly examining the chemical reactivity of commonly stored materials. Their analyses have generally determined that the most common cause of shelf-life expiration is the poor storage conditions the DoD provides the inventory. The majority of these DoD storage facilities are not temperature or humidity controlled as specified materials by the manufacturer for long life storage. Consequently, the DoD must maintain a process for testing and monitoring of such materials. This is the single largest reason for DoD shelf-life requirements to be different from commercial requirements.

The importance of controlling the environmental factors such as temperature and humidity controls has been recognized in the DoD as proven by the installation of large temperature and humidity control warehouses at DLA and different services' activities for

control of food and medical supplies. Unfortunately, similar importance has not been given for the storage of hazardous materials that require the same temperature and humidity controls for optimal life. Additionally, revision of the older MILSPEC requirements for packaging require revision for material supply contracts that use outdated and less effective or protective packaging/preservation standards than the commercial marketplace.

## C. EVALUATION OF DOD SPONSORED SHELF-LIFE REVIEWS

### 1. Arthur D. Little Laboratory Study

Arthur D. Little Laboratories were contracted by the Naval Civil Engineering Laboratory (NCEL) to review and analyze the shelf-life of fifty-five commodities that experienced high volumes of disposal and the testing criteria used to determine shelf-life extension (A. D. Little, 1992). These analyses involved utilization of the DoD acquisition specifications, storage specifications and the commercial manufacturer information databases. In the final A. D. Little report on the 55 commodities reviewed, 30 were recommended for shelf-life extension, one was recommended for shelf-life reduction, 23 were recommended for no change, and one was removed from use (A. D. Little, 1992). For these same materials, the A. D. Little study challenged the extension criteria for 36 shelf-life commodities, 18 were recommended for no change, and one was removed from use requiring no change (same item as noted above). An example of changing the shelf-life extension criteria is best presented in an example of challenges that were accepted for a specific commodity from the A. D. Little study (A. D. Little, 1992, p. 4-45) as follows:

> General Purpose Detergent, NSN 7903-00-282-9699, Type II extendible shelf-life material, shelf-life = 36 months, was analyzed with the following recommendations:
>
> 1. Shelf-Life Challenge, lengthen the shelf-life to 48 months.
> 2. Extension Criteria Challenge, perform tests for emulsifying ability, chemical stability, color and odor; extend shelf-life extension period to the full stated shelf-life with no limit on the number of extensions.

Note that in this study, a greater number of shelf-life extension criteria were challenged than those recommended for shelf-life changes. This is based on the contractor analysis and updating of the older MILSPEC parameters and performance tests required for actual extension.

***a. Government Services Administration (GSA) Materials***

Twenty seven of the original 55 materials are managed by GSA. The recommendations for shelf-life changes and challenges of the shelf-life extension testing criteria were reviewed by the GSA commodity managers and GSA laboratory chemists (Miller, 1993). Thorough investigation of past performance and extensions were conducted. The result of this analysis was that GSA agreed to modifying the shelf-life of only two commodities and revising seven shelf-life extension testing criteria. The basic argument presented by GSA is that GSA and customer warehouses are located world-wide, experiencing a broad range of temperature and humidity extremes during the year. Based on conversations with GSA personnel (Stozeck, 1995), these warehouses commonly exceed the manufacturer's recommended maximum temperature for most paints and other volatile commodities, subsequently shortening the potential shelf-life achieved under ideal storage conditions. Additionally, some packaging materials required by the acquisition specification or MILSPEC deteriorate rapidly under the exposed storage conditions and degrade the potential shelf-life of the materials stored. Prime examples of this deterioration occur when volatile materials are stored under open air conditions, subject to weather degradation of the package material due to rusting of metal containers or ultraviolet light effects on plastic containers.

***b. Defense Logistics Agency (DLA) Materials***

Thirty Seven of the original 55 materials tested are managed by the Defense Logistics Agency. The recommendations for shelf-life changes and challenges of the shelf-life extension testing criteria were reviewed by the Defense General Supply Center (DGSC), Richmond, VA, commodity managers and quality assurance personnel (Lewis, 1995). Thorough investigation of past performance and extensions were conducted by both the DGSC Quality Assurance (QA) personnel and the Engineering Support Activities (ESAs)

responsible for the prime equipment which uses the material considered for extension. The result of this analysis was that DGSC agreed to modifying the shelf-life of only one commodity. No specific reasons were presented for the exclusion of the remaining thirty-six items. However, based on discussions with DGSC Richmond QA personnel, both the less than optimal (manufacturer recommended) storage conditions and the refusal of the ESAs to approve such changes are probable explanations.

### 2. Parsons Engineering Science, Inc. Study

Parsons Engineering Science, Inc. was contracted by the Naval Facilities Civil Engineering Services Center (NFESC) to review and analyze the shelf-life of 160 commodities that experienced high volumes of disposal and the testing criteria used to determine shelf-life extension (Parsons Engineering Science, 1995). These analyses were similar to, but more thorough than, the previous A. D. Little study. This study again used the DoD acquisition specifications, storage specifications and the commercial manufacturer information databases to determine the validity of shelf-life specifications for high volume disposal materials. Of the 160 original commodities, 122 commodities have been reviewed and reports compiled into an interim report (Parsons Engineering Science, 1995). Out of the completed analyses, 82 were recommended for shelf-life extension, one was recommended for shelf-life reduction, 34 were recommended for no change, and 5 were recommended for change from Type I non-extendible to Type II extendible commodity materials. No recommendations for modification of the shelf-life extension criteria were included as part of the interim progress report (Parsons Engineering Science, 1995). No response from GSA or DLA managing activities were available for review. However, based on the additional parameters and the more thorough investigation conducted in this review, it is expected that a higher percentage of changes to commodity shelf-lives will result. General discussions with the DoD Shelf-life Committee Chairman, DLA's Mike Pipan, indicate that the improved analysis requirements were intentional and will continue to be utilized for future commodity shelf-life studies (Pipan, 1995).

## D. COST/BENEFIT ANALYSIS OF THE A. D. LITTLE STUDY

Primary in the consideration of any investment is the need to realize a benefit from the investment. A net present value analyses was conducted by this author of the A. D. Little shelf-life study using the contract investment cost of $275,000 and the disposal reductions generated by the adopted changes resulting from the study. These results are calculated in Figure 3.1 and graphically represented in Figure 3.2, reflecting a payback period of 3.75 years. The initial payback is held at zero during the first year. This is based on the fact that results were not instantaneous in terms of either DLA/GSA acceptance of the shelf-life challenges, extension testing changes, or actual implementation at the Inventory Control Point management level.

The initial investment cost for the study was assumed to be incurred at the start of year one. The investment costs were then reduced by the discounted annual benefits gained from the disposal and acquisition savings, assumed to occur at the end of each year. A discount rate of 4.35% was assumed. These benefits were based on provided by NFESC and shown in Figure 3.1. The payback period was found to be 3.75 years.

| NSN | Description | Unit of Issue (UI) Price | UI Purchased for Inventory (1 Year) | UI Disposed Inventory (1 Year) | Old Shelf-Life (SL) | New SL | Increased SL Percent |
|---|---|---|---|---|---|---|---|
| 6850-00-285-8012* | Dry Cleaning Solvent | $127.92 | 1487 | 80 | 36 | 60 | 67 |
| 7930-00-282-9699* | Detergent | $12.05 | 24192 | 1200 | 36 | 48 | 33 |
| 8040-00-582-4597* | Adhesive, Paste | $42.02 | 590 | 90 | 12 | 18 | 50 |

| NSN | Description | 1 Year Demand Value | Savings by Extending = Purchase Savings | Disposal Cost per UI | Disposal Savings 1 Year |
|---|---|---|---|---|---|
| 6850-00-285-8012* | Dry Cleaning Solvent | $190,217.00 | $25,362.00 | $44.00 | $3,520.00 |
| 7930-00-282-9699* | Detergent | $291,514.00 | $24,293.00 | $6.00 | $7,200.00 |
| 8040-00-582-4597* | Adhesive, Paste | $24,792.00 | $8,264.00 | $4.00 | $360.00 |
| | | **Total** | **$57,919.00** | **Total** | **$11,080.00** |

**TOTAL SAVINGS =PURCHASE SAVINGS+ DISPOSAL SAVINGS = $68999**

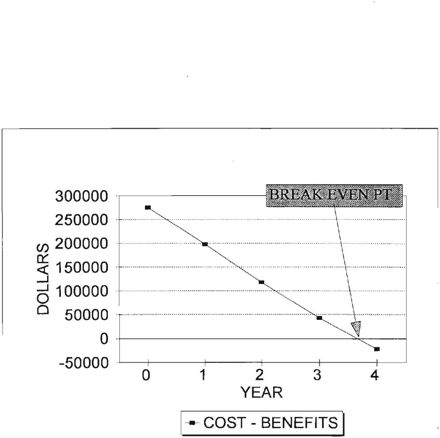
% Increased Shelf-Life = (New SL - Old SL)/ New SL

1 Year Demand Value = UI Purchased in Year * Unit of Issue Price

Savings by Extending SL (assume 100% demand)= UI Disposed * UI Price

Disposal Savings = UI Disposed * Disposal Cost/UI

Figure 3.1 A. D. Little Study Payback Analysis and Data for Accepted Shelf-Life Changes.




| YR<br>n | INTEREST RATE<br>i | DISCOUNT FACTOR<br>1/(1+i)^n | ANNUAL SAVINGS<br>Purchase savings + Disposal savings | CUMULATIVE<br>BENEFITS | COST - BENEFITS |
|---|---|---|---|---|---|
| 0 | 0 | 1.0000 | * | 0 | $275,000 |
| 1 | 0.0435 | 0.9583 | $66,123 | $66,123 | $197,414 |
| 2 | 0.0435 | 0.9184 | $63,366 | $129,489 | $117,931 |
| 3 | 0.0435 | 0.8801 | $60,725 | $190,214 | $43,064 |
| 4 | 0.0435 | 0.8434 | $58,193 | $248,407 | ($21,873) |

* NO S/L SAVINGS IN FIRST YEAR DUE TO IMPLEMENTATION DELAY ON CHANGES

Figure 3.2 A. D. Little Study Payback Analysis using a 4.35% discount rate.

Note that the Office of Management and Budget (OMB) has generated standard discount rates to be used in governmental Cost Benefit Analyses for the effectiveness of program investments (OMB Circular No. A-94). This OMB Circular establishes the real discount rates for usage in such analyses, based on the economic assumptions from the federal budget. The discount rate was established at 4.35% for this analysis based on the values in OMB Circular No. A-94, Appendix C (January, 1995 Revision), for the investment and value gained in disposal cost avoidance from shelf-life changes.

## E. THE QUALITY STATUS LIST (QSL)

Defense Management Review Decision 987 and the DoD inventory reduction plan outline the DoD material inventory management policies for the different distribution activities. These provide the basis for the development of the standardized Quality Status List and the establishment of standardized laboratories for testing of Type II extendible shelf-life materials. The initial program was established by the Defense General Supply Center, but was converted to a DoD program based on the recommendation of the DoD shelf-life committee. This program was adopted by the DoD and control assumed by the DLA Operations Support Office (DOSO).

The Quality Status List is coordinated by DLA and contains the results of tests and analyses conducted by the DoD/GSA/Commercial physical science laboratories on Type II, extendible shelf-life materials. Testing is conducted to determine if the material in question should be extended for use in critical applications, or degraded in performance and either used for non-critical applications or disposed of. These results are used by wholesale, retail, and end user activities to assist in the management of the material and provide the justification for extension of the shelf-life of the material, based on National Stock Number (NSN), Contract, and Lot/Batch numbers.

DOSO headquarters the QSL database in DGSC Richmond, where it operates the DoD QSL Model (M-204) system to provide on-line service to the DoD and other federal agencies. This is a real-time accessible system to assist users in the efficient management of

their inventories. Access is gained via voice inquiry, modem access, or through the DLA mainframe computer link. The Inventory Control Points (ICPs) and the responsible Item Managers (IMs) are able to input and edit data held on the QSL for those items which they manage. Other customers and inventory control points are able to conduct inquiries of the system only. The QSL is additionally reproduced in hard copy, microfiche, and CD-ROM formats. However, these methods lack the advantages of real time access and will be eventually phased out.

The objectives of the QSL (DOSO, DoD Shelf-Life Training Guide, 1994) are to:

1. Provide current test data to depots and customers world wide on Type II materials.

2. Prevent duplication of testing the same Contract/Lot Batch material by multiple facilities.

3. Reduce or eliminate the disposal of material by end users.

4. Reduce or eliminate the disposal work required by activities when storage sites do not have access to the latest test data.

5. Identify additional users/acceptable laboratory facilities that can provide valuable data for inclusion into the QSL database.

## F. THE FUTURE OF THE QSL

Currently, the QSL is mirrored in most ways by the Air Force Re-Inspection System (REINS), managed by the Air Force Testing Laboratory, Kelly Air Force Base, and numerous civilian DoD contractor hazardous material monitoring programs, such as the Hughes Aircraft Corporation's Hughes Chemical Management System (HMCS). The Air Force provides their testing data to the QSL, but justifies the existence of their REINS system based on unique service application, more extensive data content, and more current data than the QSL. The REINS program coordinator has total control of the program and accomplishes rapid turn

around and input of the Air Force and other laboratory results forwarded for the REINS data base.

The duplication of effort created by redundant systems provides an area of research not within the scope of this thesis. Regardless, the massive amount of data that could be accumulated through cooperative effort between these various agencies would provide an invaluable database for the QSL or some other program. This data could and should be shared, contributing to reducing the costly disposal of expired shelf-life materials. The cooperative effort of DoD contractors could also serve to reduce their own testing/evaluation costs and disposal expenses, should they choose to participate.

The inherent problems with combining the information from various sources into the central QSL database are the conversions of other database programs to the QSL format and the hardware interfaces. Neither of these issues should be insurmountable and the savings from the combined data should quickly recoup the initial investment in programming and hardware requirements. The current efforts to consolidate the various information systems is being spearheaded by DOSO/ DGSC QSL program managers and is progressing well. The largest problem being faced by DGSC is the constant need for database maintenance and data input requirements. Future growth requirements must be anticipated and planned for in the programming and hardware areas. These problems and others previously mentioned are being factored into future years' budgets by the DOSO/DGSC QSL program manager.

# IV. INVENTORY COST FACTOR ANALYSIS

## A. INTRODUCTION

The objective of the inventory model proposed in Chapter VI is to better enable the material manager to maintain the stock of materials for the purpose of issue in the correct amount, at the proper location, at the right time, and at minimal cost. The majority of the costs related to the management of hazardous shelf-life materials are the same as those for any basic inventory management system, but with some additional considerations. These basic inventory costs are the unit cost of each item purchased, the ordering cost, the holding costs, the shortage or backorder cost, and the transportation cost. In the realm of hazardous shelf-life materials there are the additional considerations of special storage and expired, damaged, material disposal, and material extension testing costs that are not found in the basic inventory model. The following sections discuss each of these cost parameters and seek to delineate the methods to incorporate the additional costs relevant to the inventory model developed. The majority of these costs are easily determined, but some involve additional factors that result in complicated analysis.

Tersine (Tersine, 1994, p. 12) and Ballou (Ballou, 1992, p. 415) show how to determine the basic costs of an inventory model. Nahmias (1982) and Silver and Peterson (1985) have studied the shelf-life (perishable goods) inventory problem and have proposed a comprehensive approach to dealing with such inventory materials. Their objective is to determine the relevant costs involved in the inventory management of shelf-life material. Then, using these relevant cost factors they determine the optimal order policy for the shelf-life material.

## B. UNIT ACQUISITION COST

The unit cost is that required to purchase the material from the source of supply. This can be the established government price for standard DLA/GSA/Navy stock material or the acquisition price for special order or non-standard materials, including the associated transportation charges. The cost of the material is assumed to be constant over all periods for all quantities purchased to fill reorder or special order requirements.

## C. ORDERING COST

The ordering costs are defined as the order processing cost for one order of material. These are the costs that can be associated with the requirement determination process, purchase request generation, and the related activities up through the order receipt process (Synergy, 1989, Encl. (1) Part V). They may include the cost of comparing different sources of supply, purchase order generation, material receipt, requisition tracking, and receipt transaction processing. DoD considers this cost to be a fixed cost regardless of order size.

DoD Instruction 4140.39 includes a complete list of the possible Inventory Control Point (ICP) ordering cost elements suggested by DoD. As a consideration, the order costs for standard stock material are less labor intensive and faster than special orders to cover shortages or other requirements. For the purpose of this study we will use an average stock replenishment cost of \$53.00/order and a special order cost of \$102.00/order, determined from cost data found in a DLA study by SYNERGY, Inc. (Synergy, 1989, p. 6).

## D. HOLDING COSTS

The holding costs of a material are the costs of keeping the physical inventory, expressed in dollars per unit per unit time. This includes the capital costs of the inventory, storage costs, costs associated with inventory loss in storage, pilferage, and the cost of material that can no longer be used due to obsolescence or expired shelf-life. Government

holding costs for non-hazardous, non-repairable material assume a relationship between the unit acquisition cost of an item and the holding cost rate for a year's time. This latter cost is expressed as the cost per year per dollar of the average inventory kept in storage. The current annual holding cost rates for consumable items at DLA activities are provided in Table 4.1 (Synergy, 1989, p. 151) and show the contributions of each component mentioned above.

These rates do not include the additional expenses associated with the storage of hazardous materials, such as climate control, fire suppression, safety precautions, and additional space requirements to segregate reactive incompatible materials, thereby minimizing the risk of dangerous reactions. Consequently, the actual storage cost component of the holding cost rate for such hazardous material can be expected to be greater than the one percent projected by DLA or specified in DOD Instruction 4140.39.

The cost of obsolete material includes the loss of material due to all factors that make the material held in inventory superfluous to the end user (Synergy, 1989, Encl.4, part IIB), including: technological obsolescence, requirement forecast errors, and deterioration beyond usefulness. This obsolescence factor is especially important for hazardous materials based on the fact that nearly 70 percent of hazardous material has limited shelf-life. Materials coded as shelf-life A-condition and CA-condition require inspection for remaining shelf-life. Materials coded as shelf-life Type I are not considered to be extendable and materials coded as shelf-life Type II (extendable after testing or inspection) that has reached its maximum allowed shelf-life must be disposed of. This increased inventory management cost serves to increase the storage and obsolesence components of the holding cost rate of hazardous material above normal levels noted by DLA and the SYNERGY study. Additionally, the longer material is held in inventory, the greater the potential for loss due to damage in handling, container deterioration, and loss due to human error during stowage, issue, or transaction recording.

Based on the previous discussion, the storage costs should be greater than the one percent average established by DLA. This thesis makes the assumption that the actual storage cost will be two percent. The additional cost of management for the shelf-life hazardous materials for special handling, inspection, testing and obsolescence determination is assumed

to add an additional two percent to the average DLA costs established in Table 4.1, resulting in an average obsolescence cost of nine percent. The obsolesence cost percentage for DPSC-M was not included in the average figure used due to its to the extremely low value. Therefore, the assumed holding cost components for the analysis are summarized as follows:

| | |
|---|---|
| Cost of Capital | 10% |
| Cost of Storage Facility | 2% |
| Other Losses | 0% |
| <u>Obsolescence</u> | <u>9%</u> |
| Total Holding Cost | 21% |

| Activity | Investment Cost % | Storage Cost % | Obsolescence Cost % | Other Losses % | Holding Rate % |
|---|---|---|---|---|---|
| DCSC | 10 | 1 | 6 | 0 | 17 |
| DESC | 10 | 1 | 8 | 0 | 19 |
| DGSC | 10 | 1 | 6 | 0 | 17 |
| DISC | 10 | 1 | 7[1] | 0 | 18 |
| DPSC-M | 10 | 1 | 1[2] | 0 | 12 |
| DPSC-CT | 10 | 1 | 7[1] | 0 | 18 |

Table 4.1 DLA Holding Costs by Inventory Control Point.

## E. EXTENSION COSTS

The costs associated with the testing of material for operational performance and the material handling required to relabel and segregate the material are the basic costs associated

[1]Assumed. Number provided to SYNERGY by DLA-OS for comparison (Synergy, 1989, p. 149).

[2]The extreme difference of this number makes it an outlier from the other data and as such, it is not included in the average determined for this category.

with the extension of expiring shelf-life material. These costs vary by the individual chemical and physical complexity of the material and the degree of testing required to prove or disprove adequate performance. Based on discussions with DLA's Mike Pipan and personal interviews with Hughes Aircraft laboratory personnel, both have determined the average shelf-life material laboratory test is approximately $300.00 per item. The cost to complete the material handling and relabeling with the new extended shelf-life is also variable and dependent on the quantity of material actually extended. This cost can be approximated knowing the hourly wage of the worker involved and the production rate at which the worker can perform the assigned tasks.

## F. DISPOSAL COSTS

The cost associated with disposal of expired shelf-life hazardous materials are the costs of removal, containerization, and transportation to the designated Hazardous Waste Disposal site. The identification of the obsolete material has already been considered to be a part of the holding costs. The disposal costs are a factor of the total cost (total cost includes the cost of repurchasing unexpired material for use, transportation, and disposal fees charged by the receiving/processing activity) of the A-condition and CA-condition materials returned by customers to a collection center or Defense Reutilization Management Office (DRMO) that must be either sold or disposed of through the Hazardous Waste reduction program. This Hazardous Waste reduction program has pioneered the installation of Hazardous Waste Minimization Centers (HAZMIN Centers) throughout DoD. These facilities serve to consolidate and redistribute A-condition and CA-condition material to the end user at no cost. This serves to reduce the quantity of hazardous material required to be disposed of through the normal hazardous waste stream. The disposal cost of A-condition material is dependent on the excess quantity of material ordered by the end user and the ability to convert the material to a CA-condition that motivates a customer to demand it. The disposal costs of the CA-condition reuse material is dependent on the actual quantity of that CA material returned to the HAZMIN Center (Piburn and Smith, 1994, p. 47).

Piburn and Smith (1994) noted in their thesis that the amount charged for disposal of the Hazardous Material by DRMO is dependent on the type of material and its weight. They assumed this charge to be equal to the per pound cost of disposal for the material, multiplied by two percent of the HAZMIN Center returned material weight, based on their discussions with HAZMIN Center's personnel at the FISC Puget Sound reutilization facility. Based on data related to the Parsons Engineering Science study, obtained from DGSC Richmond, the DRMO system now uses instead a standard per unit of issue disposal cost assigned by the type of material.

## G. SHORTAGE COSTS AND SERVICE LEVEL

Shortage costs are the costs that result when the material stocking activity is not able to provide an item when it is requisitioned. Such costs include the cost due to loss of readiness or the added expense of expediting special orders or backordering materials. In addition, the result of such a shortage produces a lack of confidence by its customers in the ability of the system to support their requirements, and often causes stockpiling of excess material by the customers as safety stock to maintain the service level they desire. Unfortunately, such stockpiling generally results in larger quantities of unmanaged expired hazardous materials, effectively increasing the overall cost to the customer and the DoD. This lack of confidence sometimes causes customers to bypass proper procurement procedures and procure material (without purchase authority) from local vendors.

Tersine (Tersine, 1994, p. 209) proposes two methods of establishing safety stocks to reduce stockouts. The first method concerns itself with known stockout costs (such as the additional expediting cost) and the second deals with unknown, undeterminable costs (such as loss of customer goodwill).

Tersine's first method includes the costs of inventory acquisition, holding, and stockouts in the development of the total average annual variable costs for managing inventories. The optimum level of customer service is obtained by taking the first derivative of the this cost equation with respect to the reorder point and setting the resulting equation

equal to zero. The result is an equation identified as the optimal Risk (or 1- Service Level) associated with the stockout. DLA and Navy item managers control their material inventories based on a similar optimality equation. In Tersine's second method, management follows the theory of unknown, undeterminable stockout costs and establishes a level of service policy designed to meet a given percentage of customer requirements. This level of service assumes an implicit tradeoff between the very expensive costs of satisfying all customer demands from on-hand stocks and the high costs incurred by backordering or spot buying every unit demanded.

## H. REGIONAL ENVIRONMENTAL RESTRICTIONS

Different geographical areas of the U.S. or overseas base activities can be restricted in the amount of hazardous material that can be held in inventory, transported, or actually released into the atmosphere. Areas such as California severely restrict the amount of Chlorinated Fluorocarbons (CFCs) and Volatile Organic Compounds (VOCs) that can be released by an agency. The release of such materials is strictly monitored and only licensed permittees are allowed to use or distribute such materials. In the case of expired materials destined for disposal, the potential for wrongful disposal represents increased risk for potential infraction of existing regulations and subsequent fines levied against the originator. These costs associated with monitored release are not considered based on the regional nature of the cost. Additionally, the costs associated with illegal (wrongful) disposal are not included in the model due to the small chance of detected occurrence.

## V. PREVIOUS INVENTORY MODELS FOR SHELF-LIFE MATERIALS

### A. INTRODUCTION

Considerable work has been previously conducted in the determination of optimal ordering policies for perishable, shelf-life inventories (Nahmias, 1982, Fries, 1975, Weiss, 1980). This chapter discusses some of the previous work accomplished in the areas of stochastic inventory models for both periodic review and continuous review inventory management systems.

### B. PERIODIC REVIEW MODELS

If one considers the case where a periodic review of the inventory level is conducted and a single period worth of inventory is maintained, the problem is similar to the simple "Newsboy or Christmas Tree" problem (Nahmias, 1982, p. 682). In this case, each order is determined for the subsequent period, no carry-over of stock is possible, and the expected inventory management costs for the period are minimized. The objective function consists of the order quantity, expected demand, ordering costs, disposal costs, and salvage values. If the shelf-life for the material is greater than a single inventory period, then the determination of the optimal order quantity is more difficult. This problem has been studied by Nahmias and the team of Silver and Peterson. The assumptions they use in the determination of the optimal order policy are as follows (Silver and Peterson, 1985, p. 414):

1. A periodic review system is used to establish reorders.
3. Orders are placed at the beginning of the period.
4. Order lead time is zero.
5. All stock arrives in new condition with full shelf-life.

6. Demand for successive periods are independent and random with a known probability distribution.

7. Inventory is issued using the FIFO policy, thereby ensuring the oldest material is issued first.

8. Units of issue that have not been issued by the time it has been in inventory for $m$ periods (where $m$ periods is the shelf-life) will be deteriorated and must be disposed.

9. There is complete backordering capability for unsatisfied demand.

10. Costs are all assumed to be linear and include acquisition, holding, shortage, and expiration.

Nahmias (1982) develops his model under the conditions of knowing the inventory of each age. The number of units that will expire $I$ periods into the future is identified as $x_i$ and the state of the inventory at a given point is represented by $X$, where;

$$X = (x_{m-1}, x_{m-2}, \ldots, x_2, x_1).$$

The order quantity is a quantity of $y$. Nahmias identifies the primary difficulty to be the developing the decision rule for the quantity of $y$ in terms of the $X$ function, the demand distribution, and all of the different unit costs. Both Nahmias and Silver and Peterson note that if one sets m = 1 then the analysis is reduced to the "Newsboy problem". The optimal general policy as derived by Nahmias (1975) is the following:

$$\textit{If } X \textit{ is such that } \sum_{i=1}^{m-1} x_i \le x_c \textit{, then order } y(x) \; ;$$

$$\textit{If } X \textit{ is such that } \sum_{i=1}^{m-1} x_i > x_c \textit{, then } y = 0 \; .$$

In these equations the critical level of inventory is identified by $x_c$ and is dependent on the different unit costs and the probability distribution of demand. The computation of the *y(x)* variable becomes increasingly complex as inventory materials move from one inventory state to another as they increase in age and are not used to fill demand requirements (i.e., the FIFO rule is ignored) or no demand requirements occur.

Nahmias concludes that the appealing properties of the optimal solution include the following;

> 1. Perishability decreases the size of the best order quantity in comparison with the nonperishable case, and the difference is largest for low values of starting inventory.
>
> 2. If the initial stock of inventory of any specific age level is increased by one unit the best order quantity decreases, but by less than a whole unit. This is because the on hand inventory has an effect on the determination of the order requirement and the amount of the effect is based on the actual age of the material. The newer the inventory, the greater the effect on the order quantity, because the inventory will last longer. (Nahmias showed that the order quantity is more sensitive to changes in newer inventory).

## C. A CONTINUOUS REVIEW MODEL

The most comprehensive work in the area of continuous review models has been done by Weiss. The inherent advantage of the continuous review process is the determination of inventory position at the time of filling each requisition and the subsequent ability to decide if an order is required. Weiss makes the determination that the optimal type of ordering policy for these types of materials must consider the associated ordering costs, inventory holding costs, disposal costs for expired materials that cannot be extended, extension testing costs on expiring materials, stockout costs, and revenue generated from filled requisitions (Weiss, 1980, p. 365). He assumes that inventory replenishment orders will arrive instantaneously (zero lead time) and that each item has a fixed lifetime of *d* periods.

Weiss assumes that the demand process is a Poisson process with a known and constant demand rate of $\lambda$ (quantity demanded per unit time). The initial inventory level is established at zero and a stock order is received equal to the order up to amount of $S$. The inventory level is decreased as each demand is satisfied based on the known demand rate or by the expiration of shelf-life for the item based on known remaining shelf life and/or failure to be extended, thereby causing removal from the issuable inventory. If an item is removed from the issuable inventory due to expiration of shelf-life, a disposal charge of $v$ is levied against the inventory account. Similarly, if the material is tested for possible extension, a testing fee of $x$ is charged against the inventory, and may be in addition to the disposal costs of $v$ if the material fails extension. As mentioned above, the inventory level can be increased at any time through ordering Q units at a cost of $K + cQ$ where $c \geq 0$ equals the price per unit and $K \geq 0$ is the cost of placing an order. The delivery of ordered materials is assumed to be instantaneous and each delivered item has a fixed lifetime equal to $d$. Holding costs are incurred for each item in inventory equal to $hW$, where $W$ is the random length of time that the shelf-life material is held as ready for issue stock. If the material is out of stock and in backorder status, the penalty cost $p$ is incurred, regardless of the length of time the inventory is in backorder status. This same assumption is used in the model presented in the next chapter.

The goal is to determine the continuous review inventory policy that minimizes the average annual total variable costs of maintaining an inventory. Such a policy must indicate when to order, determine the order quantity and the items to be issued on a one-for-one basis if the material is in stock (Weiss, 1980, p. 366). Based on these decision variables and the assumption that the holding costs are convex, non-decreasing and vanish at zero inventory, Weiss proposes that the First-In, First-Out (FIFO) inventory management system is as good as any other inventory issuing policy. Consequently, the FIFO system is the standard issuing policy adopted by the model developed in the next chapter. Weiss proposes three theorems for management consideration:

*a. Theorem 1*

*If one never orders, then there is no related ordering cost and the only cost is the penalty cost of stockout.*

This leads to the consequence that the long run expected average cost is equal to $\lambda p$. Weiss notes that under a lost-sales model, when an upper bound is place on the long run average cost (accomplished by never ordering), then changing the penalty costs, $p$, to shortage costs for the backorder model, results in the requirement that an order must be placed at some time or the long run average cost will be infinite.

*b. Theorem 2*

*If there is an optimal continuous review policy that will place an order when the inventory level is positive, then there is also an optimal continuous review policy that orders only when the inventory level is zero.*

The proof of this theorem is noted by Weiss to follow that of the dynamic economic lot size model developed by Wagner and Whitin (1958).

*c. Theorem 3*

*There is an optimal policy that is to never order or order up to S at the instant the inventory level reaches zero.*

In developing the proof of this, Weiss shows that the long run average cost is equal to the expected average cost per period divided by the expected length of the period. The optimal time for the inventory reorder process under non-decreasing costs is when marginal shortage costs exceed the long run optimal average costs which include the ordering costs, holding costs, set-up costs, material purchase cost, item lifetime, and the revenue. This has been extended to include the lost sales case using the long run average cost, resulting in Weiss' determination that "if it pays to order at all, then we should order at the times that the inventory is depleted." This is under the assumption that "the penalty cost is incurred if there is a demand when the stock is depleted even though the demand can be satisfied instantaneously by placing an order" (Weiss, 1980, p. 368). Using an argument presented by Hadley and Whitin, the optimal policy is (- 1 , S) since one can instantly fill any demand and not pay any penalty costs under the assumption of instantaneously satisfied stock reorders.

Weiss additionally proposed another version of the backorder model, which assumes that all backordered (stockout) demands are eventually filled, either immediately or later after reordering as in the (- 1, *S*) case. The costs of this model are similar to those previously noted, except that the per unit penalty cost $p$ is replaced with the shortage cost function $p(W)$, where $W$ is the time that it takes to satisfy the demand.

Nahmias (1982) notes that Weiss' paper was the only work published at that time that considered the continuous review perishable inventory problem. No other references on continuous review inventory approaches were discovered during this thesis literature review.

The practical application for such a model is limited, because an inventory manager would tend to reduce the level of inventory and related loss of inventory by using backordering, single unit demands, and continuous review under zero lead time. This limits the application of such a model to the optimal policy of reordering if and only if the inventory level is zero. Under the conditions of non-zero lead time or large quantities of demand, such a policy would not perform well as noted by Nahmias (1982).

# VI. SHELF-LIFE MODEL DEVELOPMENT

## A. INTRODUCTION

The previous chapters presented the background for the model to be developed in this chapter. The model is for a continuous review inventory management system and includes costs to order, hold, dispose of, extend, and test the material prior to extension. Since shortage costs are not known for military shelf-life material the standard service level, known as the "fill rate" is assumed.

## B. STOCHASTIC ECONOMIC ORDER QUANTITY (EOQ) MODEL

### 1. Background

The classic Economic Order Quantity (EOQ) model, developed in the early 1900's, is known as the deterministic inventory technique (Heizer, 1993, p. 564). The basic EOQ model seeks to offset the costs of holding material in inventory with the costs of ordering such material, resulting in the minimization of the total average annual costs. This does not account for the costs associated with risk and uncertainty (Tersine, 1994, p. 205). The model to be described below does address these latter costs.

The assumptions used in the formulation of this model are:

#### *a. The Distribution of Demand is known*

That the distribution of demand is constant is valid considering the simplicity of the model and that the majority of demands will be based on routine requirements that occur during normal operations. A known percentage of the inventory is assumed to expire during each period and is considered as part of the routine demand. Net demand will include the demand based on these routine requirements, the percentage of inventory expiring under normal conditions, less the quantity of inventory extended during the cycle. The distribution assumed is the Normal distribution.

### b. *Lead time is known and constant*

Lead time can be controlled through wholesale supplier relations and considerably shortened with the use of direct vendor delivery for stockout materials requiring backorder.

### c. *All receipts of inventory are instantaneous and orders are received in full*

Materials that are ordered to fill backorders or regular inventory replenishment will arrive in full and at one time. Processing into inventory will take zero time to accomplish.

### d. *No quantity discounts*

There is no purchase price discounts for materials stocked by the supply system at any level of inventory management. Under the Defense Basic Operating Fund (DBOF) requirements, prices are based on the price dictated by the item manager as necessary to recoup the monies required to stock, distribute, and repurchase new material for stock. These prices will be assumed as constant.

### e. *Ordering, Setup, Holding, Extension and Disposal Costs*

These costs are assumed to all be known and to remain constant over the inventory cycle. All of these costs will be dependent on the specific hazardous material considered. The extension costs will vary based on the complexity of the test, the quantity of inventory that must be segregated and relabeled if extended, downgraded, or moved to disposal.

### f. *Shelf-life material in inventory will have a known expiration that can be extended*

The material in the inventory has expiration dates established by the shelf-life code determined by DoD and the date of manufacture. These dates of expiration can be extended based on laboratory testing for performance or other means, thereby reducing the amount of hazardous material waste generated and decreasing the associated demand.

## 2. Model Development

### *a. Safety Stock*

The inventory stock of the independent demand system is commonly separated into the working stock, planned for normal demand use during the established time period, and the safety stock, which is held in inventory as a buffer against higher than normal demand rates. Safety stock is defined as the expected net inventory at the time a replenishment arrives. A positive safety stock is kept on hand as a cushion against stockouts due to the random nature of demand during lead time (Tersine, 1994, p. 206). This safety stock is held in inventory based on the inventory manager's determination of the inventory level that is the most efficient, such that the cost or risk of stockout is reduced to an acceptable level.

The consequence of having a positive safety stock is increased holding costs and decreased stockout costs. However, there is a decreasing marginal benefit with each additional unit of safety stock.

### *b. Reorder Quantity*

The optimal reorder quantity and the reorder point can be determined from minimizing the expected annual Total Variable Cost function with respect to those decision variables. The expected annual Total Variable Cost (TVC) function can be defined as:

**TVC = Purchase Cost + Ordering Cost + Holding Cost**
**+ Backorder Cost + Disposal Cost + Extension Cost**

The parameters and decision variables used in developing the TVC are defined as follows:

**$Q$ = Order quantity**

**$C_b$ = Cost of a backorder per unit**

**$C_d$ = Cost of disposal per unit or salvage value per expired unit ($D > 0$ for disposal and $D \leq 0$ for salvage)**

**$C_o$ = Cost per order**

**$C_p$ = Purchase cost per unit**

**$C_t$ = Cost of shelf-life material extension (testing , segregation and labeling cost)**

**$N_t$ = Annual number of shelf-life extension tests**

**$R$ = Expected annual demand based on customer requisitions**

**$X_d$ = Expected shelf-life inventory quantity disposed due to expiration per year**

**$X_e$ = Expected shelf-life inventory quantity extended per year**

**$I$ = Annual holding cost rate, including expired material awaiting disposal or salvage**

**$SS$ = Safety stock**

**$L_d$ = Demand during procurement lead time**

**$\sigma_{LT}$ = Standard deviation of lead time demand**

**ROP = Reorder Point**

**$E(L_d > ROP)$ = Expected lead time demand greater than the reorder point, or expected number of stockouts when an order arrives**

Using these variables, the equations for each cost factor are as follows:

1. **Purchase Cost** - The cost to purchase the inventory is based on the cost per unit times the expected net annual demand, where the net annual demand is the annual demand based on customer requisitions plus the quantity of expired material disposed minus the quantity of shelf-life material extended; that is, $( R + X_d - X_e)$ = expected net annual demand.

$$C_p\ (R + X_d - X_e)\ .$$

2. **Ordering Cost** - The ordering cost is based on the cost per order times the number of orders placed in a year. The number of orders placed in the year is based on the expected net annual demand occurring over the year divided by the quantity ordered.

$$C_o\left[\frac{(R + X_d - X_e)}{Q}\right].$$

3. **Holding Cost** - The holding cost is the sum of the average on hand inventory and the quantity of safety stock times the annual holding cost per unit held as inventory. Average inventory is defined as one-half of the order quantity plus the extended shelf-life material. The annual holding cost is equal to

the annual holding cost rate times the procurement cost of the inventory per unit.

$$IC_p \left[\frac{Q + X_e}{2} + SS\right].$$

4. **Backorder Cost** - The backorder cost is the cost of a backordered unit times the expected number of backorders during the procurement lead time. This quantity is then multiplied by the number of reorder cycles per year to obtain the expected annual backorder costs.

$$C_b \left[\frac{(R + X_d - X_e)}{Q}\right]\left[E(L_d > ROP)\right].$$

5. **Disposal Cost** - The disposal costs are calculated by taking the cost of disposal per unit times the quantity of units disposed of per year. The actual quantity of disposals is determined by the historical quantity of material sent to DRMO and tallied either locally or in the Defense Reutilization Management System (DRMS).

$$C_d\,(X_d).$$

6. **Extension Cost** - The extension cost is the actual cost incurred by testing the material to determine if the material can be extended times the number of tests conducted during a year.

$$C_t\,(N_t).$$

$N_t$ is determined by the number of times in the defined demand period that the material is tested for possible extension. This is implicitly a factor of the feasibility of the test based on the cost of the test(s) required, quantity, and value of the material being tested and as discussed in section D of this chapter.

7. **Reorder Point (ROP)** - The reorder point (ROP), often referred to as the low limit of the inventory, is the sum of the average demand during the procurement lead time and the additional quantity of safety stock maintained. This quantity of safety stock is dependent on the inventory manager's established service level, based on the customers needs. Based on the assumption that the demand is normally distributed, the ROP is:

$$ROP = L_d + z\sigma_{LT} \;;$$

and, therefore,

$$SS = z\sigma_{LT} = ROP - L_d \;.$$

The expected Total Annual Variable Cost function is then determined by combining the equations of the six previous sections into the following equation:

$$TVC = C_p\,(R + X_d - X_e) + C_o\left[\frac{(R + X_d - X_e)}{Q}\right] +$$

$$IC_p\left[\frac{Q + X_e)}{2} + SS\right] + C_b\left[\frac{(R + X_d - X_e)}{Q}\right]\left[\,E(L_d > ROP)\right]$$

$$+ \; C_d\,(X_d) + C_t\,(N_t)\;.$$

The Economic Order Quantity equation is then determined by taking the first derivative of the TVC equation with respect to Q and setting it equal to zero, resulting in the following:

$$Q = \sqrt{\frac{2[R + X_d - X_e]\,[C_o + C_b\,E\,(L_d > ROP)]}{IC_p}}\;.$$

The optimal value for the reorder point is determined by taking the first derivative of the TVC with respect to ROP and results in the following equation for the risk of stockout:

$$P\ [\ L_d > ROP] = \frac{Q\ I\ C_p}{C_b(\ R + X_d - X_e)}\ .$$

This equation is then used to determine *z* from the Normal table. Once *z* has been determined, ROP and $E(L_d > ROP)$ can be computed as follows:

$$ROP = L_d + z\sigma_{LT}\ ;$$

$$E\ (L_d > ROP) = Q(1 - Service\ Level) = \sigma_{LT}(f(z) - z\ P(L_d > ROP)).$$

This equation for $E(L_d > ROP)$ is only valid for the Normal distribution for lead time demand. Note that f(*z*) is the density function of the standardized Normal distribution (i.e., mean = 0, standard deviation = 1). The high limit for the material is then determined using the following equation:

$$HIGH\ LIMIT = ROP + Q\ .$$

Because the optimal Q and $P(L_d > ROP)$ formulas contain both Q and ROP, an iterative process is needed to find the optimal Q and ROP. The first step of the solution procedure is to determine the initial Q, where;

$$Q = \sqrt{\frac{2[R + X_d - X_e\ ]\ [C_o]}{IC_p}}\ .$$

This initial Q value is then used in the service level formula to determine the expected value of lead time demand that exceeds the ROP,

$$E\ (L_d > ROP) = Q(1 - Service\ Level)\ .$$

Then the following equation is used to determine the value of $z$ for which $E(L_d > ROP)$ at the selected service level,

$$E\ (L_d > ROP) = \sigma_{LT}(f(z) - z\ P(L_d > ROP))\ .$$

The process for finding the $z$ value is to assume successive $z$ values and compute the $E(L_d > ROP)$ for each $z$ until a value of $z$ is found which gives the $E(L_d > ROP)$ that is equal or near equal to that computed from the service level equation above. In the process, the corresponding $P(L_d > ROP)$ value is determined from the complementary cumulative distribution function for the standardized Normal distribution. If a table of successive $z$ and corresponding $P(L_d > ROP)$ values is developed, it can be used in subsequent iterations to reduce the subsequent search times for the new $z$ values. An example of such a table is shown in the next section (see Table 6.1)

Substitution of this value for $P(L_d > ROP)$ into the optimal risk formula allows for the determination of $C_b$. By rearranging the variables we obtain the equation for $C_b$ as follows,

$$C_b = \frac{Q\ I\ C_p}{P\ [\ L_d > ROP](\ R+X_d-X_e)}\ .$$

Once the value for $C_b$ is determined, it is used in the previously derived optimal EOQ equation (shown below) to determine the next value of Q.

$$Q = \sqrt{\frac{2[R + X_d - X_e]\,[C_o + C_b\, E\,(L_d > ROP)]}{IC_p}}\ .$$

The associated ROP value is:

$$ROP = L_d + z\sigma_{LT}\ .$$

This Q value becomes the starting point for the next iteration. The iterative process model is continued until the Q values converge.

## C. MODEL EXAMPLE

The following example illustrates the process for determining the optimal Q and ROP. Given that a shelf-life material has the following parameters:

**$R$ = 1000 units/yr**

**$X_d$ = 100 units**

**$X_e$ = 90 units**

**$C_o$ = \$500.00 (assumed)**

**$C_b$ = \$1000.00 (assumed)**

**$C_p$ = \$20.00/unit**

**$L$ = Lead time for an order = 2 months**

**$L_d$ = R( L/12 months) = 1000( 2/12) = 167 units**

**$\sigma_{LT}$= Standard deviation of lead time demand = 100 units**

**$I$ = .23**

**SL= Service Level = 95%**

The first step of the solution procedure described in the previous section is to determine the initial Q, where;

$$\textit{Initial } Q = \sqrt{\frac{2[R + X_d - X_e\,]\;[C_o]}{IC_p}}\;;$$

$$\textit{Initial } Q = 468.6 = \sqrt{\frac{2[1000\ +100\ -\ 90\ ]\ [500]}{(.23)20}}\;.$$

This initial Q value is then used in the service level formula to determine the expected value of lead time demand that exceeds the ROP.

$$E\ (L_d > ROP) = Q(1 - \textit{Service Level}) = 486.6\ (1 - 0.95\ ) = 23.4\ .$$

Then the following equation is used to determine the value of $z$ for which,

$$E\ (L_d > ROP) = \sigma_{LT}(f(z) - z\ P(L_d > ROP)) = 23.4\ ;$$

where f($z$) is the value of the density function of the standardized Normal distribution (mean = 0, standard deviation = 1).

The process for finding the $z$ value is to assume successive $z$ values and compute the E($L_d$ > ROP) for each $z$ until a value of $z$ is found which gives the E($L_d$ > ROP) of 23.43. The results are shown in Table 6.1 on the following page. For this example, the result is $z = 0.39$.

The corresponding P($L_d$ > ROP) is determined from the complementary cumulative distribution function for the standardized Normal distribution. The result is P($L_d$ > ROP) = 0.3483 as found in Table 6.1 on the following page.

| z | f(z) | P ($L_d$ > ROP) | E($L_d$ > ROP) |
|---|---|---|---|
| 0 | .3989 | .5 | .3989 |
| 1 | .2420 | .1587 | 8.33 |
| .25 | .3687 | .4013 | 28 |
| .29 | .3825 | .3859 | 27.06 ~ Second E($L_d$ > ROP) |
| .35 | .3572 | .3632 | 24.8 |
| .39 | .3697 | .3483 | 23.38 ~ Initial E($L_d$ > ROP) |

Table 6.1 Successive *z* values used in the iterative process for optimal Q and ROP.

We next substitute this value for P($L_d$ > ROP) into the equation for $C_b$ .

$$C_b = \frac{Q\ I\ C_p}{P\ [\ L_d > ROP](\ R + X_d - X_e)}\ ;$$

$$C_b = \$6.13 = \frac{468.6 * .23 * 20}{.3483(\ 1000 + 100 - 90)}\ .$$

Once the value for $C_b$ is determined, it is used in the previously derived optimal EOQ equation (shown below) to determine the next value of Q.

$$Q = \sqrt{\frac{2[R + X_d - X_e]\ [C_o + C_b\ E\ (L_d > ROP)]}{IC_p}}\ .$$

$$= 532 = \sqrt{\frac{2[1000 + 100 - 90]\ [500 + 6.13(\ 23.38)]}{(0.23)20}}$$

The associated ROP value is:

$$\boldsymbol{ROP = L_d + z\sigma_{LT} = 167 + (.39)(100) = 206}\ .$$

This Q value of 532 becomes the starting point for the next iteration. The iterative process model continues until the Q values converge. For this example the convergence Q value is the next Q value; namely, 542 units. The final ROP value is 196 units.

Note that as the Q value increases, the ROP decreases during the iterative process. The Navy's inventory control point model stops after determining the first Q and ROP since that gives the highest ROP value, and hence more safety stock, lowest Q, and hence cheaper investment in a procurement. In the case of shelf-life material a high ROP would result in more disposals than a lower one and is therefore definitely not preferred.

## D. DETERMINING IF MATERIAL SHOULD BE EXTENDED

The determination of whether or not material should be extended can be based on the replacement purchase, extension, and disposal costs (if the material was to be disposed) of the extended material compared to the costs of testing for extension approval. The basic premise behind the use of testing is that of pollution, disposal, and replacement costs avoidance. A marginal analysis can be used to determine whether an extension test is economical. First, consider the costs to dispose of and replace material if it weren't extended. The cost is equal to the sum of the disposal cost for the old material and the purchase cost and the ordering costs of the new material. These costs are given by the following formula:

$$X_e\left(C_d + C_p + \frac{C_o}{Q}\right)\ .$$

Next, we assume all $X_e$ units are tested at the same time and that the total cost is $C_t$ . Then it is cheaper to test if:

$$X_e\ [C_d + C_p + \frac{C_o}{Q}] \geq C_t\ .$$

Finally, dividing through by $X_e$ gives the following inequality:

$$[C_d + \frac{C_o}{Q} + C_p\ ] \geq \frac{C_t}{X_e}\ .$$

The left side of the above inequality represents the net marginal per unit cost to dispose of one expired unit of an item and to procure and order one new unit. The right side of the inequality represents the per unit testing cost. Thus, if the net unit cost to dispose of and acquire more replacement material is greater than the per unit cost of testing, then testing for shelf-life extension is appropriate.

For example, if the parameters from the example in section C of this chapter are used in the above formula, then:

**Q = 542 units**

**$X_e$ = 90 units**

**$C_o$ = \$500.00**

**$C_t$ = \$300.00**

**$C_p$ = \$20.00/unit**

**$C_d$ = \$3.00/unit**

$$[20 + 3 + (500/542)] > 300/90$$

$$\$17.92 > \$3.33$$

Based on this calculation one would decide to test for shelf-life extension because the per unit cost of disposal and relacement (left side) is definately greater than the per unit cost of testing for extension.

## E. AN ALTERNATIVE APPROACH TO DETERMINING IF EXTENSION TESTS ARE COST EFFECTIVE

This approach is to compare the TVC value using the equation derived in section B of this chapter with a TVC value assuming $C_t(N_t)$ and $X_e$ are zero and setting $X_d = X_e + X_d$ in the TVC equation of section B. If this second TVC value is less than the first then it would be more economical not to test for extension of shelf-life, or a value of $C_t(N_t)$ can be determined above which testing is not economical. Note that the reason for setting $X_d$ in the "no-testing" TVC equation equal to $X_e + X_d$ "assuming testing", is that in the "no-testing" case all of any inventory which could be extended would be sent to disposal along with that which could not be extended. If the comparison between the TVC's focuses on $C_t(N_t)$ then the most economical number of tests per year, $N_t$, could also be determined.

# VII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## A. SUMMARY

This thesis was initiated to develop a stochastic continuous review inventory model which would incorporate the value gained from decreased inventory disposal costs for expired hazardous material categorized as hazardous waste by extending its shelf-life. Chapter I presented the problem, stated the objective of the thesis and the associated research questions, and previewed the research methodology. Chapter II discussed the issues associated with shelf-life extension and the procedure for getting approval for such extensions. Chapter III discussed the existing DoD shelf-life extension programs and the results of the cost/benefit analysis based on the A. D. Little study. The shelf-life investigations conducted to date indicate a relatively short payback period for the investment based on OMB prescribed discount rates. The chapter concludes with a discussion of the Quality Status List which contains the results of past shelf-life tests. Chapter IV examined the inventory cost parameters associated with the management of inventories of hazardous material. These became part of the model in Chapter VI. Chapter V discussed previous inventory models developed by other authors. Chapter VI presented a stochastic inventory model for establishing the optimal order quantity and reorder point for an established service level. The iterative process for determining the optimal order quantity and reorder point is described and a sample calculation presented. Chapter VI also presented two models for deciding whether or not it is economical to conduct testing for the purpose of extending the shelf-life of an item.

## B. CONCLUSIONS

The potential for hazardous material reductions in the DoD can be increased by adopting commercial standards, revising existing military standards, and decreased inventory storage levels through the use of vendor direct-delivery or vendor recycling of expired

materials. The use of commercial shelf-lives under the less-than-optimal storage conditions experienced in the DoD requires laboratory analysis. The potential for considerable savings in disposal costs and inventory procurement resulting from extending the shelf-life of inventories of hazardous material justifies the expense for chemical analysis and laboratory testing of shelf-life materials and validation or modification of their assigned shelf-life codes. Chapter III showed that the shelf-life study programs such as that previously conducted by A. D. Little and currently in process by Parsons Engineering Science can be cost effective in terms of the projected savings compared to the investment. Based on the information discussed in Chapter II, the process by which recommended shelf-life changes are adopted can be streamlined from the Item Manager through the Engineering Support Activity responsible for the end item application or use and ultimately to the item procurement agent.

The stochastic Economic Order Quantity model developed in Chapter VI demonstrates the positive effect that extension of shelf-life materials through testing or other methods can have in reducing the Reorder Point and the related Safety Stock. The reduction of expired material disposals is seen to have a positive effect in terms of replacement inventory acquisitions, reduced backorders, and decreased disposal costs.

## C. RECOMMENDATIONS FOR FURTHER STUDY

The DLA Quality Status List should be adopted as the standard repository of shelf-life information regarding testing results and changes to the existing shelf-life codes. The duplication of effort among the different agencies (e.g., DLA and GSA) and military branch item managers should be reduced by consolidation of test facilities. This would allow for more rapid application of test results at both the inventory manager and procurement level and a more real time updating of the QSL database.

The use of real-time change notification and implementation at the ICP level should be done in such a manner that the item procurement agent is immediately made aware of a shelf-life change and can implement changes to existing delivery orders and pending delivery contracts prior to receipt by the managing ICP. This effort would greatly reduce the quantity

of products requiring subsequent shelf-life reviews. Reduction of such shelf-life reviews would reduce the labor investment at both the wholesale and retail levels of inventory for shelf-life management. This will also decrease the individual investment by each service or agency in the areas of testing, evaluation and quality control, information dissemination, and ultimately reduce the inventory and disposal of hazardous shelf-life materials. Further investigations into the application the models developed in this thesis offer the potential for improved shelf-life management and disposal savings. Additionally, simulation modeling is needed to determine if the $X_d$ and $X_e$ terms are valid representations of disposal and extension costs in the model developed in Chapter VI. Finally, use of the alternative approaches at the end of Chapter VI to determine if testing is cost effective offer the potential for determining if real testing costs for shelf-life material are economically justifiable.

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